Natural stone in Norway: production, deposits and developments

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The natural stone industry has, during the last two decades, experienced a tremendous growth both on a global scale and within a Norwegian context. At the present time, the natural stone industry contributes significantly to total Norwegian mineral production and export. The production of larvikite is, by far, the most important part of the industry, followed by slate and metamorphic flagstone. Future reserves of these important resources are considered to be large. In addition, a diversified natural stone industry aimed for local and domestic markets is growing in most parts of the country, driven by an increased use of stone for buildings domestically, and by the need for paving stones in urban areas. There exists a considerable potential for the development of new natural stone deposits, as well as revitalising old quarries in the light of the expanding and increasingly diversified use of stone. However, the possibilities for the development of new deposits for export-oriented production is probably limited to a few geological provinces containing unique rock types. Environmental issues and land use regulations will undoubtedly influence natural stone exploitation in Norway, and there are considerable future challenges concerning the handling of waste from production, 'peaceful' co-existence between industry and community, and the integration of information on natural stone deposits into plans for land use.

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Introduction

Building stone differs from other mineral resources in several ways. First of all, stone quarrying is about the art of collecting whole, massive pieces of rock, without the need for crushing and grinding and separation of individual minerals. Furthermore, stone processing does not include removal of 'unwanted' components from the rock; it simply deals with a more or less advanced way of shaping pieces of rock into finished products. In addition, the market for stone products depends more on the consumer's personal taste and on fashion trends than the chemical and physical quality of the material concerned.

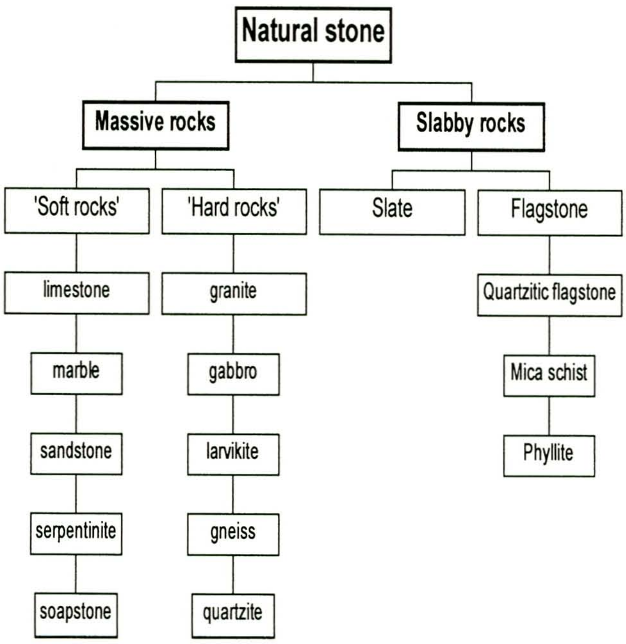

Fig. 1. Industrial classification of natural stone (types found in Norway).

In many places around the world, the stone industry is based on the collection and shaping of field stones and simple quarrying of soft and hard stone for local building purposes. For small-scale, local-market production of stone, the basic requirements are rocks that are easily worked with a minimum of labour (Shadmon 1997). An attractively coloured granite is not of commercial interest if it takes an excessive number of working hours to shape a block or a brick for construction. A 'boring', grey granite may, however, be very interesting if the cleavage properties facilitate the shaping of the blocks. This perspective differs completely from the search for stone for the international market. Most of the export quality stone of the world ends up as polished slabs on floors, walls and as tombstones. The aesthetic aspect (e.g. the colour and structure of the rock) is here far more important in the pricing of stone than physical properties. Predominantly, rare colours such as blue, yellow, pure white and deep black are highly priced, whilst rocks of more 'ordinary' colours obtain lower prices. For raw blocks, the most exclusive rocks may be 20 times more expensive than the cheapest.

All over the world we have seen, during the last decades, an expanding business in stone, both for local/domestic and for international markets (Conti et al. 1990). This is not only because of a short-term fashionable trend, but rather more a 'catching up' on 70 years of concrete hegemony in construction.

Building stones are often classified according to their technical quality and usability. A standardised, international classification scheme does not exist, but it is common, as shown in Fig. 1, to differentiate between massive stone (extracted in large blocks) and slabby stone, extracted as slabs which are cleaved along a planar structure, such as sedimentary layering or metamorphic foliation. Massive stone is further divided into 'soft' varieties such as carbonates and serpentinite, and 'hard', essentially quartzo-feldspathic rocks.

Exploitation of natural stone

The most important aspect in the exploitation of natural stone deposits is the need for extracting large and whole blocks and slabs of rocks with a uniform quality. This is done by wedging, careful blasting and primary sawing, or a combination of these methods (Figs. 2 and 3). Sawing, especially by diamond wire, is most applicable to rocks with low or intermediate hardness, such as limestone, marble, slate and serpentinite, but is also widely used for feldspathic igneous rocks and, to some extent, also for granites. However, blasting and wedging is still the most common extraction method for hard siliceous rocks. Some of these rock types have excellent natural splitting properties due to more or less visible structural anisotropic features, such as directionally distributed minerals or microfractures. Experienced quarry workers know how to make use of these directions in order to facilitate the extraction process. The structural features are also of importance to the commercial value of the finished products. Foliated or layered rocks will obviously have improved technical properties when cut parallel to the lamination instead of perpendicular to it. In addition, the colour and structure, which contribute to the aesthetic quality, vary according to cutting directions. In some extreme cases, rocks must be cut in a specific direction to have any commercial value at all, such as the Norwegian larvikites.

Fig. 2. Larvikite quarry, close to Larvik, Southeast Norway. A combination of drilling/blasting, diamond wire sawing and wedging is applied in the extraction process.

Fig. 3. Diamond wire sawing applied in the Løvgavlen marble quarry, Fauske (northern Norway).

Another important aspect in the production of rough blocks for the international market is the need for heavy machinery in the quarries (Fig. 2). A standard size for trade blocks is 2.4 x 1.2 x 1 m (ca. 8 tonnes). Most suppliers will be asked for even bigger sizes, up to 30 tonnes, to feed the giant frame saws in Italy or other countries producing finished products. The blocks should be well-shaped and rectangular, with no veins, cracks or inclusions. For small blocks and blocks with such 'faults', the price may be reduced by up to 70% if one is fortunate to find a buyer for them.

The need for large blocks creates a waste problem in natural stone quarries, and generally the percentage of waste is well above 50%. In some Norwegian quarries, it may be as high as 95%. The proportion of waste is a good indicator of extraction costs, which in Norway vary from USD 150 to USD 1000 per m^3 for commercial blocks, reflecting differences in uniformity, fracture density and splitting properties. Only the most exclusive rock types can be produced at such a high unit cost. For most granites, prices (per m^3) are lower than USD 500, and thus the waste ratio should be below 80 % and the deposits homogenous and massive.

The varying price for raw blocks is highly dependent on the colour of the rocks; rare colours give higher prices on the world market. Blue, yellow, deep black and pure white are among the most expensive colours, whilst pink and grey rocks are low-priced. Generally speaking, all rocks showing an attractive play of colours, such as iridescence in feldspars, are highly priced.

Important geological aspects in the evaluation of natural stone deposits

Given the complex market mechanisms for natural stone, including local needs for raw materials, as well as trends and behaviour of the global market, some knowledge of markets for finished products is a prerequisite in geological investigations of stone deposits. In any case, there are some important geological aspects that need to be focused upon, including:

- Geological aspects influencing *the uniformity of rock colour and structure*, such as veins and dykes, inclusions and segregations, foliations and layering and other structural elements.
- Geological aspects influencing *the block and slab size*, such as fracture density, folds, 'open' foliations, remanent stress fields and weathering and deloading features.
- Geological aspects influencing *the quality of the rocks*, in the shorter or longer terms, such as deteriorating minerals and minerals causing staining of the rock (e.g. sulphides and oxides), porosity and mineral texture.

- Geological aspects influencing *the workability of the rocks*, such as preferred orientations of minerals and microfractures.
- *Geometry and size* of the deposits

The testing of physical properties of rocks can be of assistance, especially for the documentation of quality to customers and end-users. A variety of standardised tests exist, covering the strength of the rocks to loading and other mechanical influence, to resistance to weathering and chemical attacks (Alnæs 1995). At present time, test methods and product requirements are being harmonised at a European level. However, the tests are not of any significant help for evaluating the commercial value of the deposits.

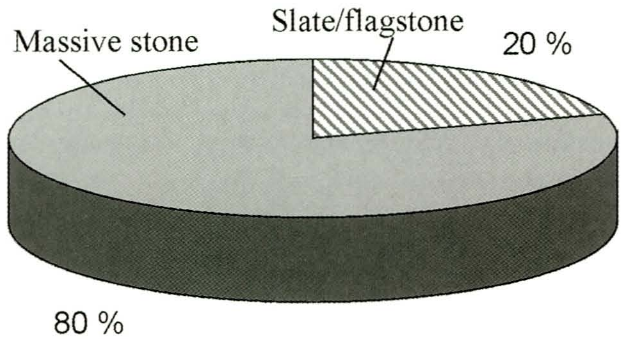

Fig. 4. Slate/flagstone and massive stone production in Norway, 1999. Larvikite production contributes to approximately 88% of the total massive stone production. Figures are based on production value from primary producer (blocks or slabs), thus excluding processing companies buying raw material from other producers.

Norwegian stone production

After a significant growth in the 1980's, the production of natural stone in Norway remained at a fairly stable level throughout the 1990's, although a small increase has been noted in the past few years. The total production value is estimated to USD 100 million in 1999 (Fig. 4); the export value was approximately USD 85 million (Figs. 5 and 6). Import of stone amounted to only USD 5 million. The export of raw blocks of larvikite contributes the major part (close to 80%) of the total exports. This attractive type of monzonite with a bluish play of colour, which is quite unique to SE Norway, is used for flooring and building facades all over the world.

Production of quartzitic flagstone and phyllite is also of great importance, essentially for domestic use, although a part of the production is exported. Some exclusive types of marble are exploited in Fauske, northern Norway (e.g., the pink and white 'Norwegian Rose'), whilst several other types of granitic gneiss and also serpentinite and soapstone are produced by smaller companies around the country as shown in Fig. 7.

Most Norwegian stone companies are very small, even in a Norwegian context; only 10 companies have more than 20 employees. However, the few large companies are expanding their share of the market. Today, for example, almost 90% of the flagstone and phyllite production is controlled by *Rieber & Søn ASA*, and the largest larvikite producer (*Lundhs labrador AS*) controls approximately 70% of larvikite production. Of great importance for parts of the stone industry, in recent years, has been the deliveries of 50,000 m^2 of slate and marble for the new Oslo Airport at Gardermoen, which opened on October 8th 1998.

There have been several developments of small-scale production units of granite and flagstone for local markets in recent years, due to an increasing use of roughly hewn and hammered stone in urban environments. Of greater interest for the export market are two deposits of exclusive stone that

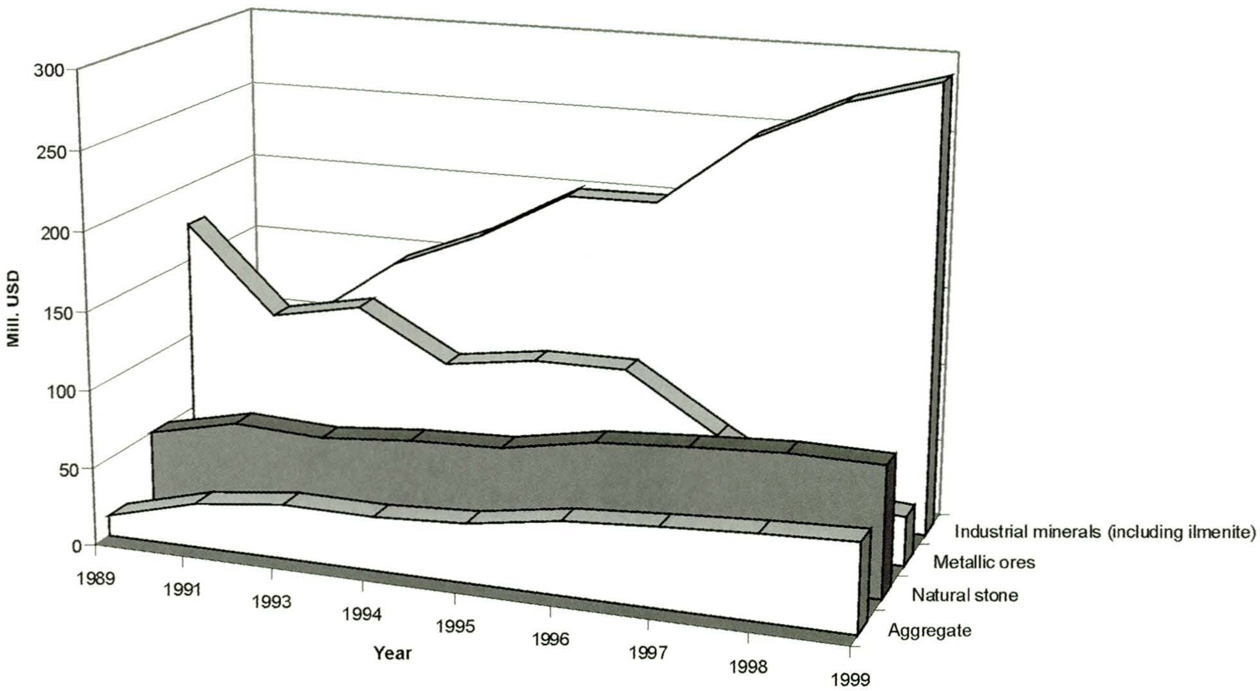

Fig. 5. Export of Norwegian mineral resources during the last 11 years.

have recently been put into regular production. One is the *Labrador Antique* anorthosite (brown with a blue play of colour) in SW Norway (Heldal & Lund 1995), produced by *Granitt 1893 AS* since 1996. The other is an emerald-green massive quartzite (*Masi Quartzite*) from northernmost Norway. Production of this quartzite was started in 1999 by two companies, *Fuchsite AS* and *Masikvartsitt AS*. The emerald-green colour is due to a high content of a Cr-bearing mica, fuchsite. Ongoing prospecting activities include soapstone and marble.

All in all, the Norwegian stone industry is moving ahead, albeit at a slower rate than in the 1980's, backed by the export of exclusive rock types and a continuing increase in the size of the domestic market. One trend is clear: large companies are growing larger at the expense of smaller producers who are being bought out by the larger companies who dominate the industry and market.

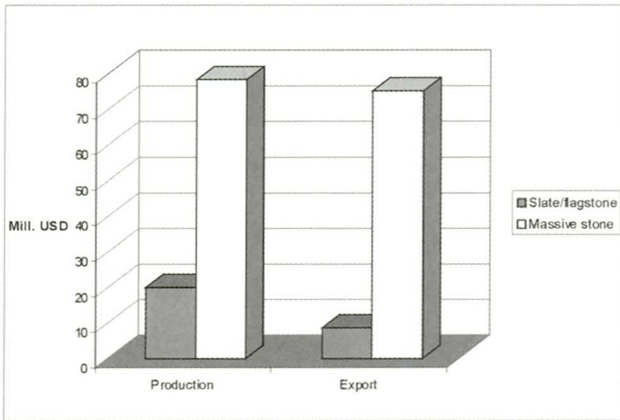

Fig. 6. Production versus export for Norwegian natural stone commodities.

Resource potential

Norwegian bedrock geology provides a considerable variety of lithologies, although predominantly metamorphic and igneous rocks, which have either been extracted as building stone in the past, are being extracted at present, or may be of future interest as sources of building stone.

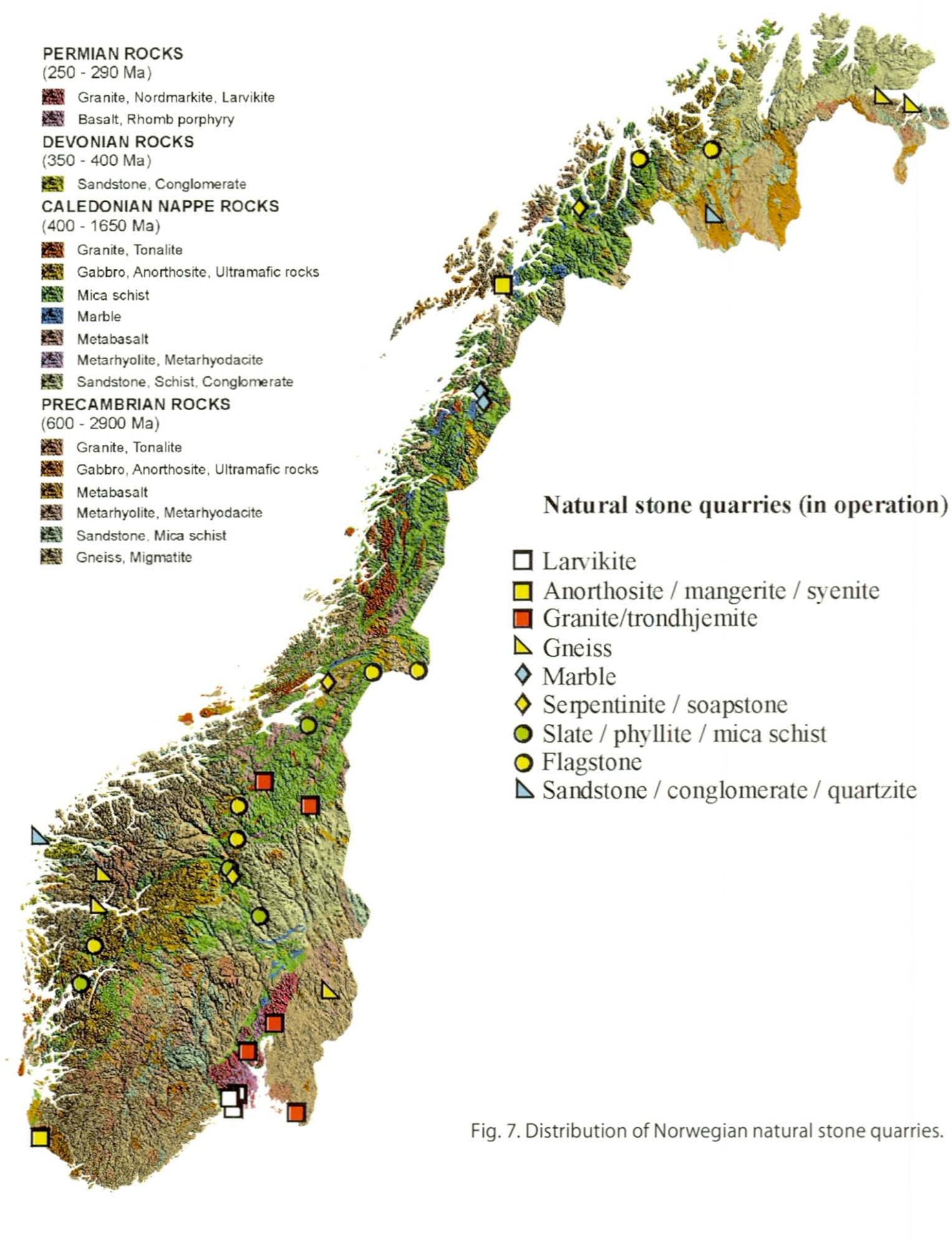

Fig. 7. Distribution of Norwegian natural stone quarries.

Igneous rocks occur in all three main units of Norwegian bedrock geology; in the Precambrian basement, the Caledonian mountain chain and the Permian Oslo rift (Fig. 8). *Precambrian* granites occur predominantly in the southeast part of the country. Colour generally varies from grey to pink and red, and both fine-grained and coarse-grained types occur. One of the best known deposits, the grey Iddefjord granite (Fig. 9A), has been quarried for 150 years (Gautneb et al. 1999). Other Precambrian granites of interest, although currently not under exploitation, include the red granites around the town of Grimstad (Fig. 9B), South Norway (Heldal 1992), and the pink and green, epidote-bearing porphyritic granites described from several localities within the Precambrian basement of southern Norway. Large massifs of feldspathic igneous rocks occur in northern Norway (the Lofoten massif) and in the southwest (the Rogaland Igneous Complex). A black monzonite is quarried in the Vesterålen area, Nordland (Fig. 9C), and a brown anorthosite containing chatoyant labradorite in Rogaland (Fig. 9D). In both areas, there is considerable potential for the development of other deposits (Heldal & Lund 1995).

Lower Palaeozoic granitoids occur mainly in Central and North Norway. The composition ranges from granite to tonalite and granodiorite, and the colour is mainly white to grey, with some pink varieties. In Central Norway there are several small bodies of white trondhjemite (leuco-tonalite). Two deposits are extracted today, at Støren (Sør-Trøndelag: Fig. 9E) and Tolga (Hedmark), though mainly for domestic and

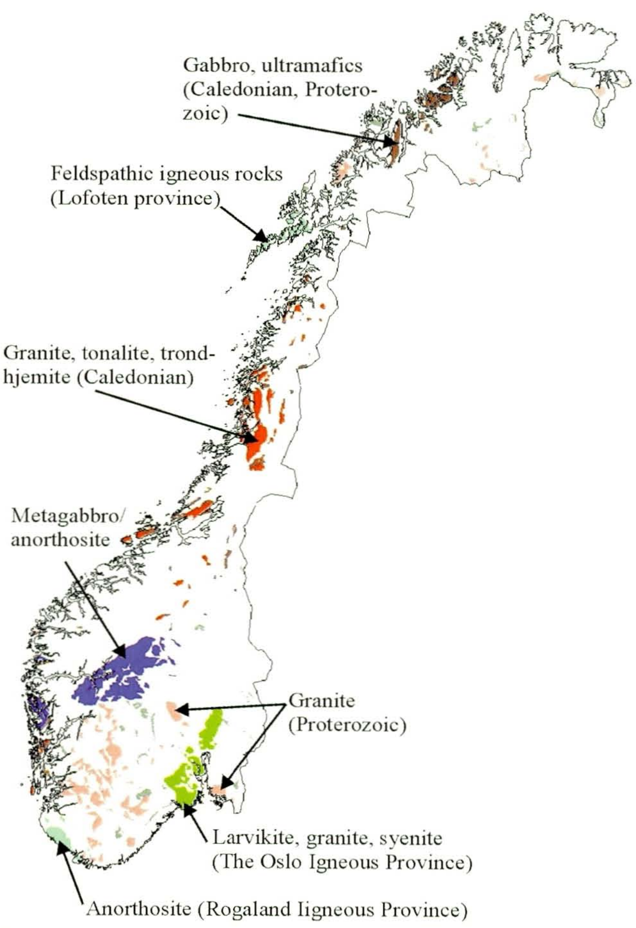

Fig. 8. Igneous rock provinces in Norway.

Scandinavian markets. Farther north, in Nordland county, there are a number of large intrusive bodies of grey and pink granite. There are no operating quarries in these granites, but a number of potential deposits, especially of porphyritic varieties (Fig. 9F), are known from SW Nordland (Heldal 1994). Smaller deposits of Early Palaeozoic granites occur on the west coast of Norway and include pink, grey and green types.

The youngest igneous rocks in Norway are found in the Oslo area. Production of larvikite is today the most important part of the Norwegian stone industry, and around 20 quarries are operating in this area. Best known are the light coloured *Blue Pearl* (Fig. 10A) and the dark *Emerald Pearl* (Fig. 10B) varieties, but other types are also extracted (Fig. 10C, D). Several research projects in the area are being carried out to investigate the possibilities for underground quarrying and the future resource potential of larvikite (Heldal et al. 1999, Kjølle et al. 2000). Farther north, pink and brown granite and syenite are found. There is a long tradition in the extraction and use of these rocks, but only two quarries are still in operation in the brownish Røyken granite (Heldal & Gautneb 1996; Fig. 10E) and one in the Grorud syenite (Fig. 10F).

A huge part of the Norwegian bedrock consists of various types of Precambrian gneiss (Fig. 11). *Granitic gneiss and leptites*, predominantly pink, are common rocks within the basement in both southern and northern Norway, and three deposits are being extracted on a small scale, in the Steigen area (Nordland: Fig. 12C) and the Flisa area (Hedmark: Fig. 12D, E). Several other deposits are being investigated. *Migmatites* have become increasingly popular in the international market during the last decades, due to the wavy structure of such rocks, their attractive colours and excellent technical properties. In Norway, special attention should be paid to the easternmost parts of the Precambrian, such as in the Varangerfjord area in northernmost Norway. Here, in the Varanger Gneiss Complex, there are several deposits of red, bluish grey and grey migmatites. Two quarries in the area have recently been opened, at Nyelv (Fig. 12B) and Bugøynes (Fig. 12A). Migmatites of dimension stone quality are also found in the southeastern gneiss region. *Augen gneiss* is mainly formed by dynamic metamorphism and deformation of igneous rocks. Usually, large feldspar grains occur as 'augen' in a fine-grained and foliated groundmass, and such gneisses may display a great variety of colours (Fig. 12F). However, because of the strong planar layering, slabs should be cut only parallel to this. In the Norwegian bedrock, augen gneisses occur in several localities; and there are many varieties – 'serizzo' types, pink, violet and greenish in hue (Heldal & Lund 1993). Today, only 2 small operating quarries exist, in the vicinity of Førde, on the west coast of Norway.

Although marble is not a dominant rock type in Norwegian bedrock, there are several deposits of attractive marble which have been exploited for more than 100 years. Most of these occur within the thick marble formations of northern Norway (Fig. 13). Best known abroad is the pink and white *Norwegian Rose* from Fauske (Vogt 1897, Heldal & Gautneb 1995, Melezhik et al., this volume: Fig. 14A). Other, less well known types include massive and layered, pink (Fig. 14D, E), grey (Fig. 14B) and greenish calc-silicate marbles (Fig. 14C),

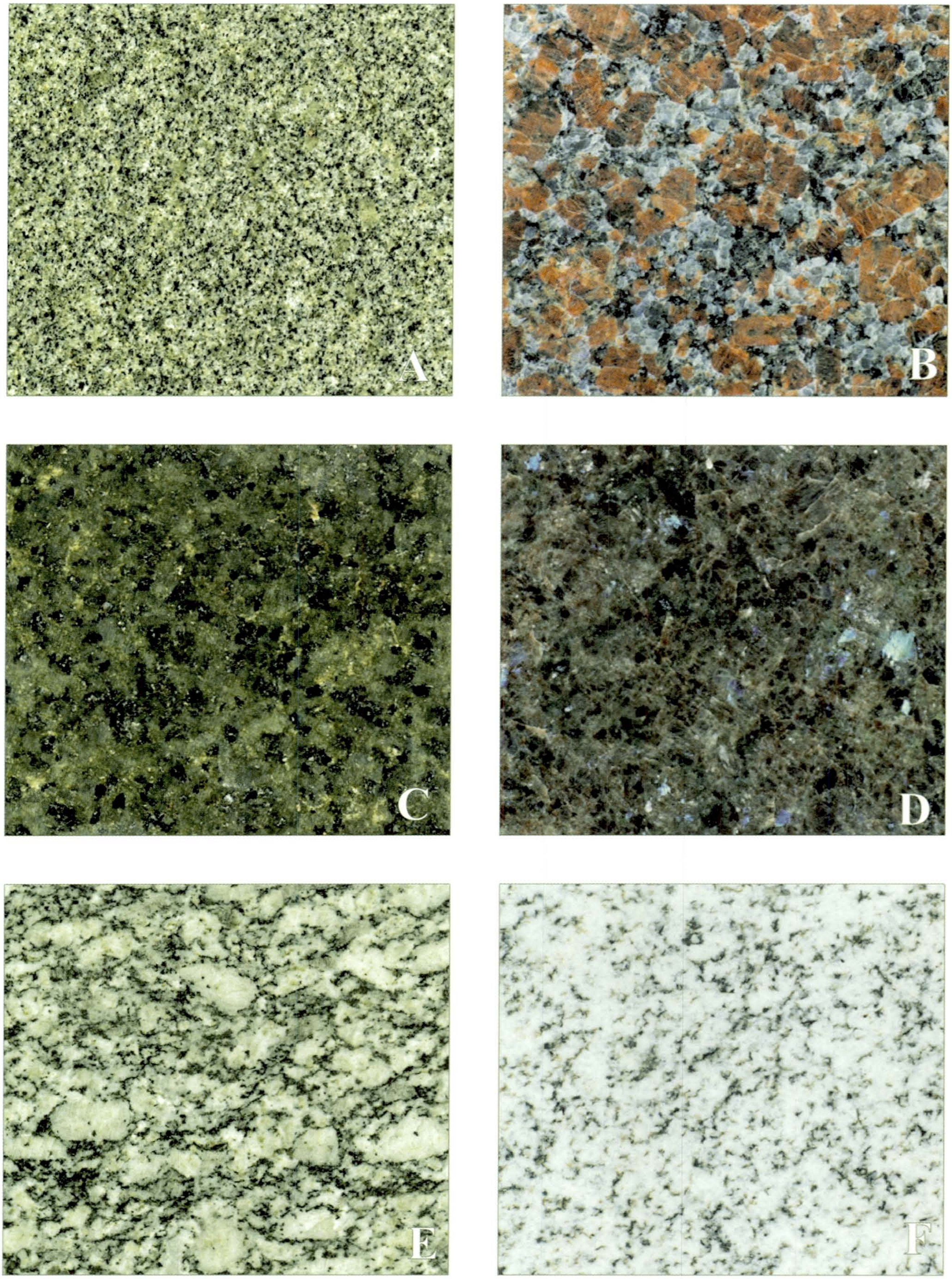

Fig. 9. Selection of Norwegian igneous rocks used as natural stone from the Caledonian and Precambrian provinces, polished samples. A: Iddefjord granite, Østfold (Precambrian), B: Grimstad granite, Aust-Agder (Precambrian), C: Lødingen mangerite, Nordland (Precambrian), D: Helvik anorthosite, Rogaland (Precambrian), E: Vevelstad granite, Nordland (Caledonian), F: Støren trondhjemite, Sør-Trøndelag (Caledonian). Size of images appr. 70% of sample. Colour may deviate from the original.

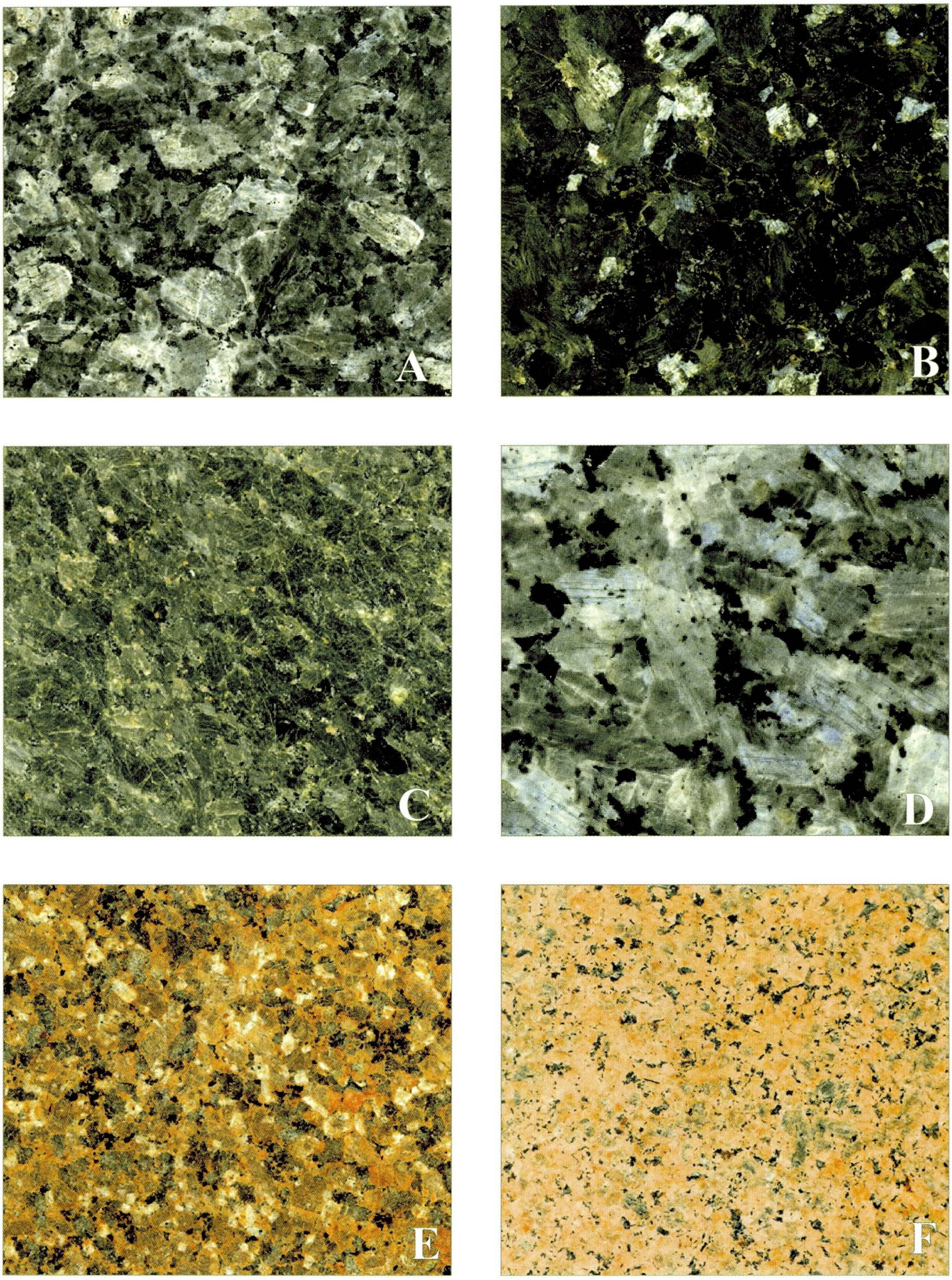

Fig. 10. Selection of igneous rocks from the Oslo Igneous Province used as natural stone, polished samples. A: pale larvikite (Tvedalen), B: dark larvikite (Klåstad), C: dark larvikite (Bergan-type), D: pale larvikite (Malerød-type), E: granite (Røyken), F: syenite (Grorud).
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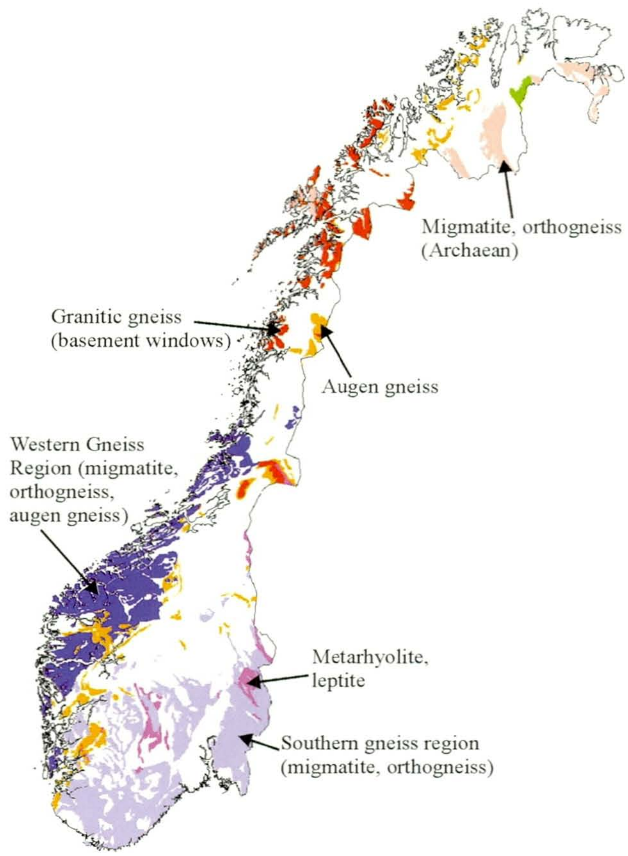

Fig. 11. Gneiss provinces of Norway.

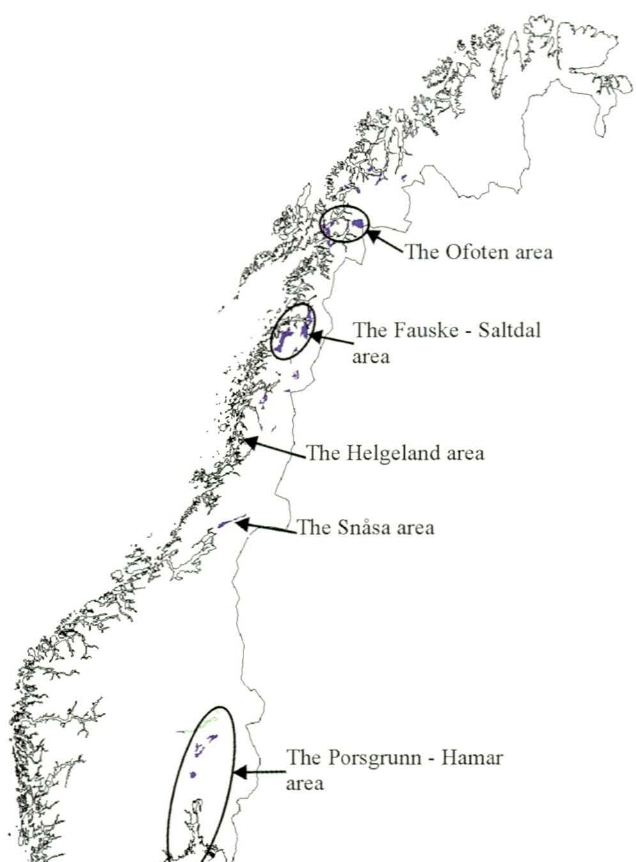

Fig. 13. Marble provinces in Norway.

Fig. 15. Slate and flagstone deposits in Norway.

and white dolomite (Fig. 14F) and calcite marbles. Limestone and fine-grained marble occur to a limited extent in Southeast Norway, close to Oslo. There is still a considerable potential for the exploitation of interesting deposits of both marble and limestone.

Production and use of slate and flagstone for roofing, cladding and paving has long traditions in Norway, and during the last decade Norwegian industry has become a world leader in the production of metamorphic flagstone. Large deposits of grey, flaggy quartzite, black phyllite and mica schist are found in many parts of the country (Fig. 15), especially within the Caledonian nappes in Central and northern Norway. The largest production units are located in Alta, North Norway (Heldal et al. 1997: Fig. 16A) and Oppdal (Central Norway: Lund et al. 1998, Fig. 16B), while several other, smaller producers are scattered around the country (Lund 1979, Gautneb & Heldal 1994, Heldal & Sturt 1996, Heldal & Lund, this volume: Fig. 16D). Black phyllite is produced mainly in Central Norway, the most important variety of which is the Otta phyllite (Fig. 16C).

Soapstone has been used as building stone in Norway since the time of construction of the medieval churches and cathedrals. Soapstone, which dominantly consists of the soft mineral talc, is extremely easy to carve and saw, and its high heat capacity makes it an excellent stone for use in fireplaces. Today, there are two producers of soapstone – at Otta (Fig. 16E), and in the Balsfjord area in the northern part of the country. Currently, there is a resurgence of interest in prospecting for soapstone deposits, and at NGU there are several ongoing projects with this goal in mind.

Closely related to soapstone are serpentinites, where the

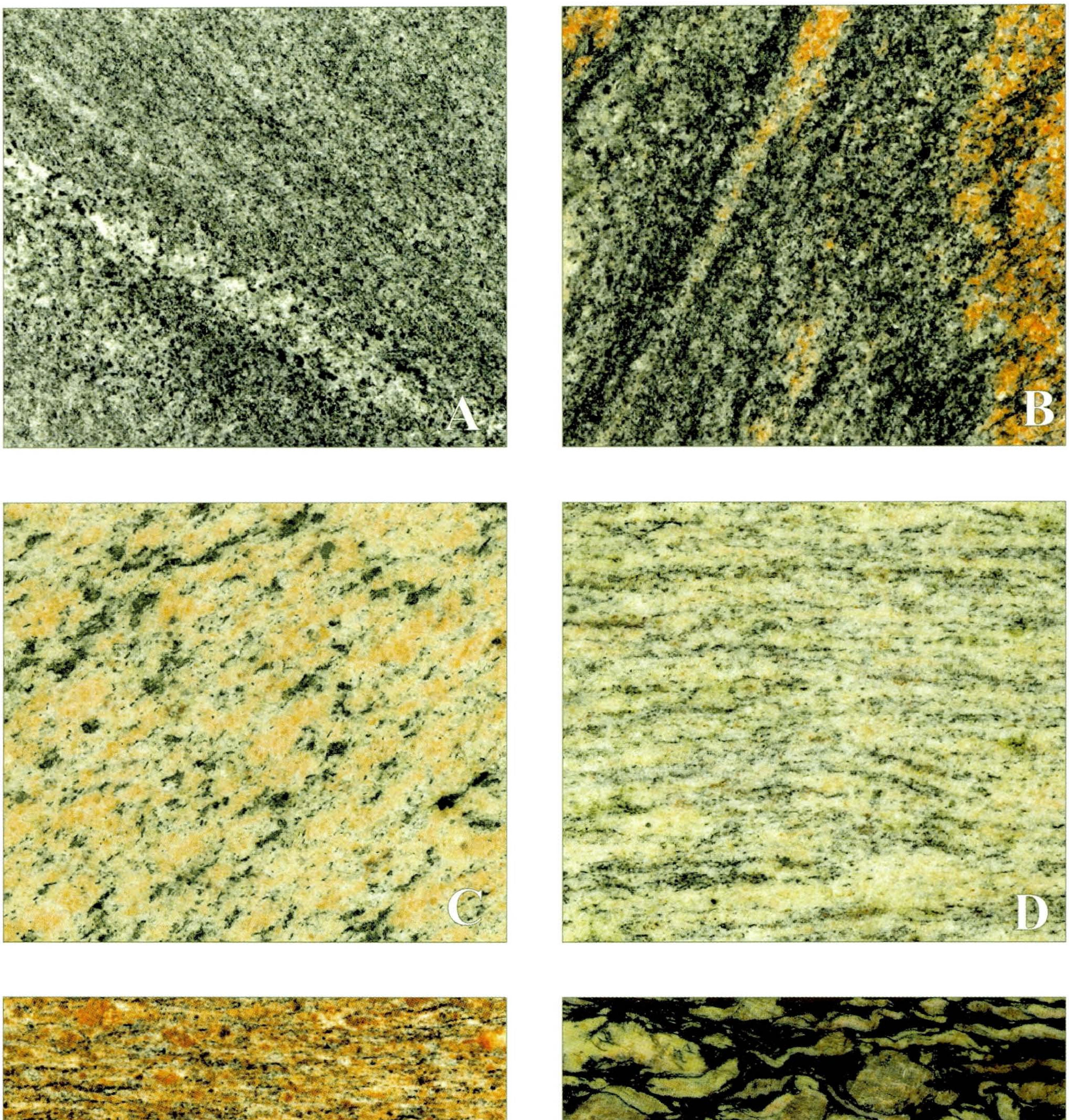

Fig. 12. Selected gneisses from different regions in Norway used as natural stone, polished samples. A: migmatite Sør-Varanger, Finnmark, B: Migmatite Nesseby, Finnmark, C: granitic gneiss Steigen, Nordland, D: granitic gneiss Flisa, Hedmark, E: rhyolitic gneiss Flisa, Hedmark, F: augen gneiss Oppdal, Sør-Trøndelag. Size of images appr. 70% of sample. Colour may deviate from the original.

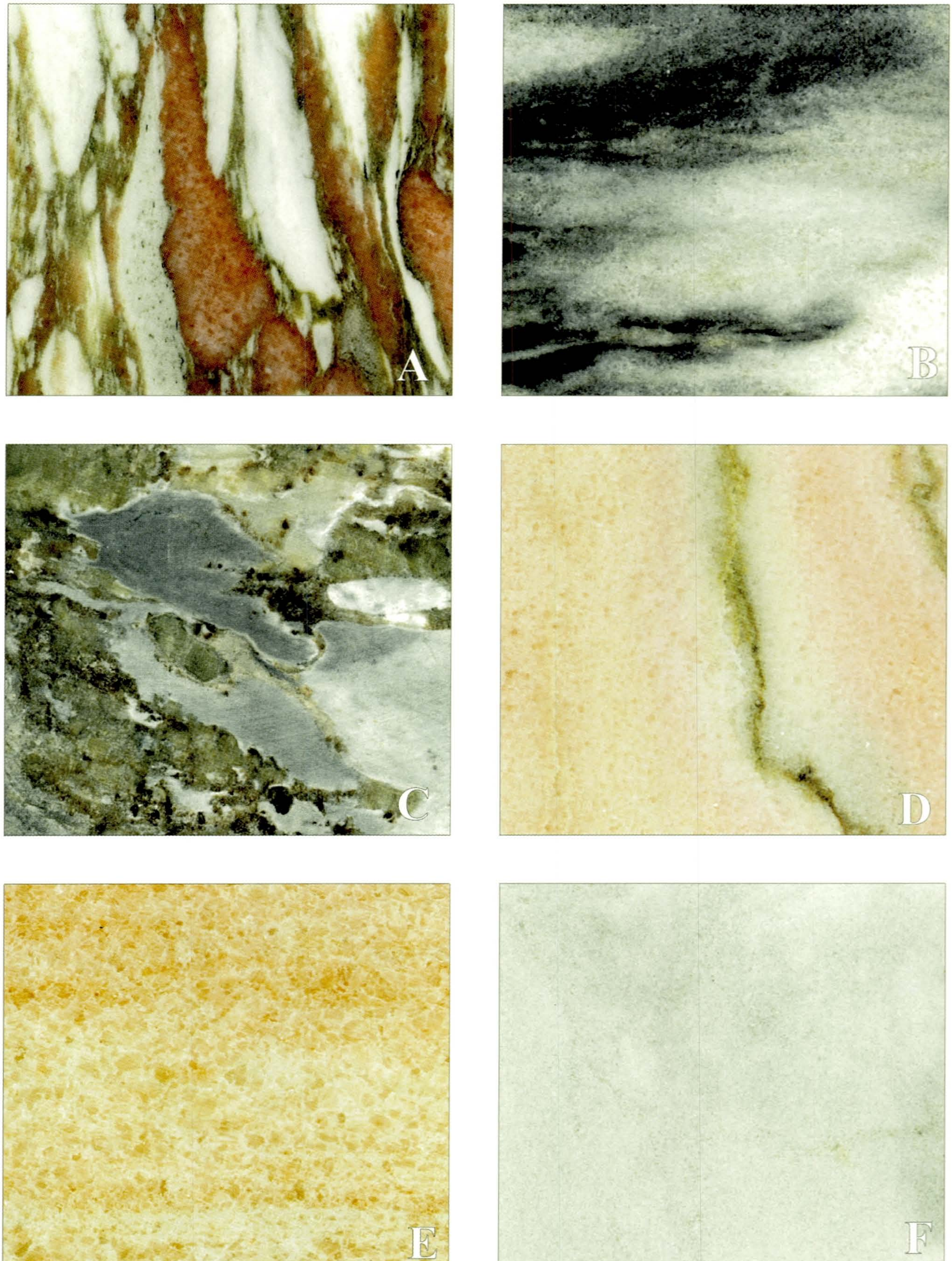

Fig. 14. Selected Norwegian marbles used as natural stone, polished samples. A: calcite-dolomite marble Fauske, Nordland, B: calcite marble Fauske, Nordland, C: ophi-calcitic marble Bindal, Nordland, D: calcite marble Skjerstad, Nordland, E: calcite marble Namsos, Nord-Trøndelag, F: dolomite marble Fauske, Nordland. Size of images appr. 70% of sample. Colour may deviate from the original.

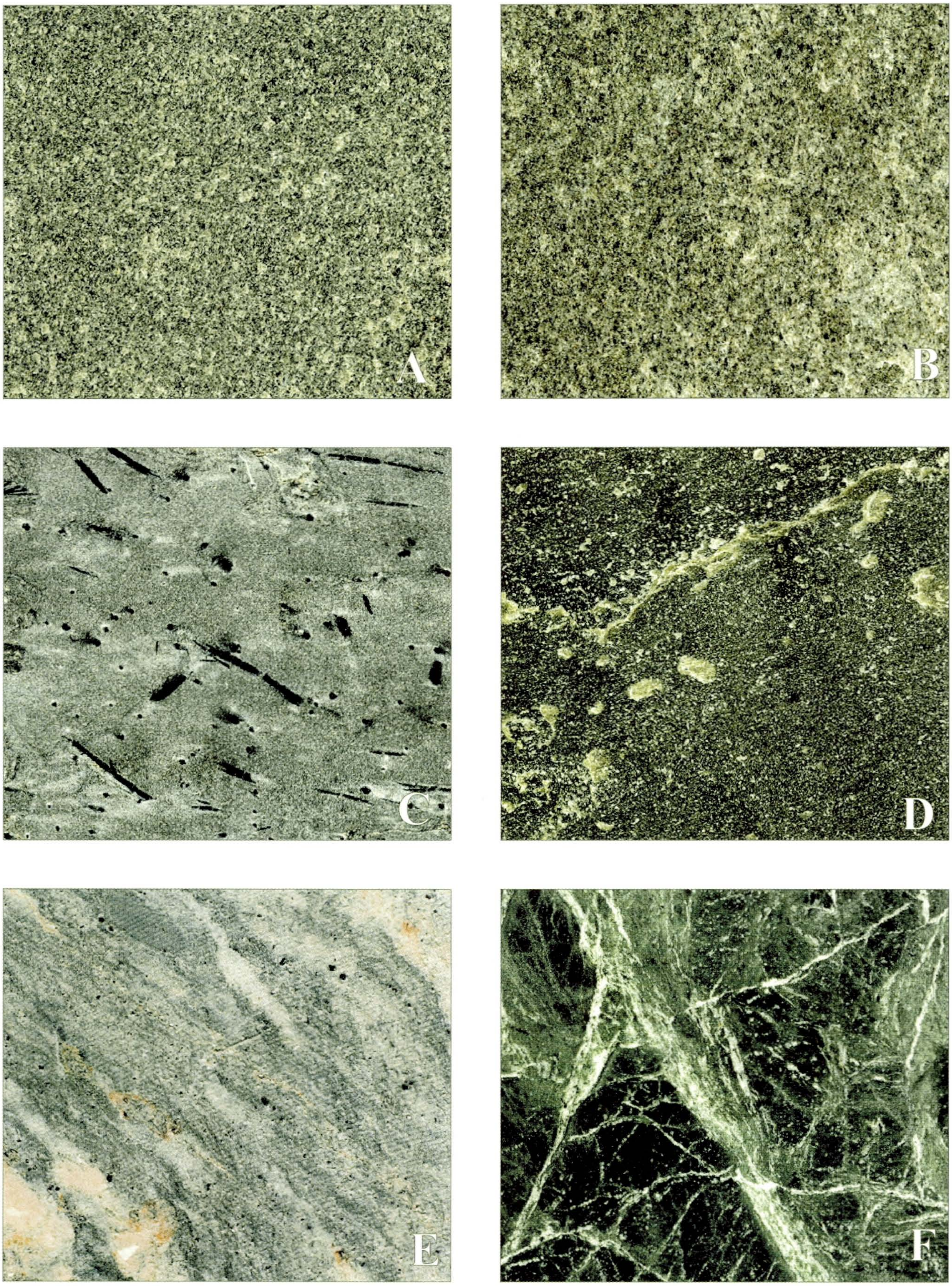

Fig. 16. Selected Norwegian slates, flagstones and ultramafic rocks used as natural stone. A: Alta flagstone, Finnmark (cleaved surface), B: Oppdal flagstone, Sør-Trøndelag (cleaved surface), C: Otta phyllite, Oppland (honed surface), D: Voss flagstone, Hordaland (cleaved surface), E: Otta soapstone, Oppland (honed surface), F: Sparbu serpentinite, Nord-Trøndelag (polished surface). Size of images appr. 70% of sample. Colour may deviate from the original.

green mineral serpentine is the dominant constituent. In the stone industry, serpentinite is often called 'green marble' because of its structure and similar technical properties. Deposits commonly occur together with soapstone deposits. Only one deposit is extracted today, namely the Solberg serpentinite in Central Norway. Two varieties, a dark green and a pale green variety (Fig. 16F), are produced and are popular flooring materials in Scandinavia. Both in this and in other parts of Norway, there are large serpentinite provinces, in which the likelihood of finding new occurrences is thought to be quite considerable. Of special interest are 'oxidised', red serpentine conglomerates in the Otta area.

Massive quartzites are found in many places. The most attractive type is the emerald-green quartzite (Masi Quartzite) from Finnmark, from which a trial production has begun. Two companies are now prospecting these resources. Large occurrences of red quartzite and quartz-rich sandstone are found in Southeast and northernmost Norway. Conglomerates occur in a great variety in Norway from the Devonian 'multicoloured' (polymict) conglomerates on the west coast, to greenish and reddish varieties in other places such as eastern Finnmark, in the far north.

Perspectives for the future

The natural stone industry in Norway can be expected to increase both in terms of the volume of production of established stone types and in the development of an increased range of products. However, the type of extreme growth that the industry experienced during the 1980's is unlikely to be repeated in the future.

There will probably be continued growth of small-scale production units for local and domestic markets, working on an increasing number of rock types and deposits. The large-scale production aimed for export will probably be further concentrated in the hands of fewer and larger companies, and due to the increasing competition in the market only the most exclusive rock types will be of future interest. In Norway, some of the most interesting areas for natural stone prospecting are the provinces of feldspathic igneous rocks, and we will probably see the development of new commercial types of anorthosite and larvikite in the future. Granite and gneiss occurrences will mainly be of interest for domestic markets, with few exceptions, whilst some new, exclusive marble types may still be possible to exploit.

The focus on environmental issues in Norway as in other parts of the world, is growing, and the mineral industry is particularly sensitive to this. The production of natural stone is, in a global sense, sustainable, 'clean' and consumes less energy than synthetic building materials, but better solutions for the handling of waste are clearly needed. Furthermore, with the expansion of urban areas and regulations concerning land set aside for agriculture, recreation and natural habitats, land-use conflicts are increasing. It is thus important to identify both the reserve potential around known deposits, and the localities and/or areas in which interesting stone types occur. This is of particular importance, so that local and regional planners are able to consider these possibilities in terms of designating future potential industrial areas. It is also necessary to identify potential environmental impacts, and to suggest solutions towards their mitigation. In this context the considerable databases held at NGU can play a significant role.

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